Untethered Magnetic Haptic Interface

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I. Introduction

A haptic device enables the user to interact with a virtual environment through the use of physical touch.

Current mechanical haptic devices use linkages and motors to create forces to simulate the environment. These introduce friction and inertia, which can make simulating small high-resolution forces difficult.

The purpose of this project is to create an untethered haptic device using electromagnets and magnetic stylus, eliminating physical connections and the problems of mechanical friction and inertia.

A primary purpose of this device is to provide medical professionals a more realistic training experience for delicate procedures such as eye surgery.

II. Project Objectives

1. Spooling Method: Design a method to build tapered electromagnetic coils.
   - Must be reusable.
   - Must withstand coil baking temperature.
2. Thermal Control System: Design a cooling system to maintain the coil at operating temperatures during extended use.
   - Must be non-ferromagnetic to limit system interference.
   - Cannot exceed 400 Watts of power consumption.
   - Must maintain coil temperature below 60°C for user safety and coil integrity.

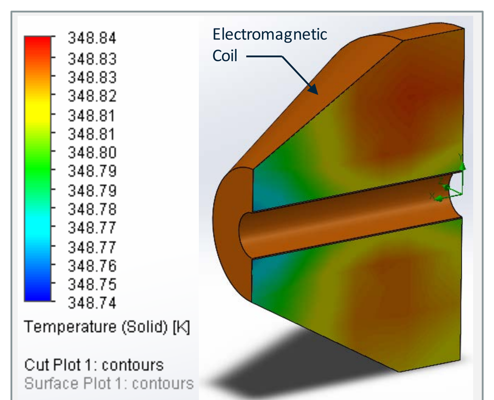
III. Spooling Method

1. Successfully releases coil upon disassembly
   - Falls apart easily when releasing the coil
   - Simple to reassemble for reuse.
2. Can withstand baking temperature
   - Melting temperature of wire bonding agent: 150 - 200°C.
   - Melting temperature of aluminum: 660°C.

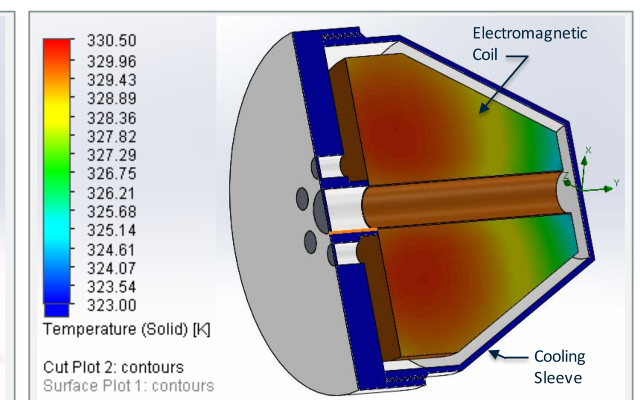
IV. Computer Simulation

A set of eight identical cooling sleeves, each housing an individual electromagnet, was determined to be the method most suited to the project needs. The first stage of testing for the cooling sleeve was conducted using a SOLIDWORKS flow simulation model, the results of which are shown below. The temperature distribution of both the working fluid and electromagnet can be shown as the fluid moves through the center of the electromagnet and then around its outside edge.

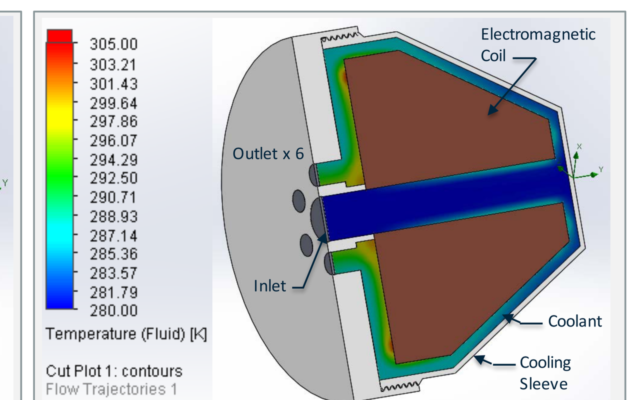
Initial Conditions	Results
Flow rate = 0.025 L/s	Max coil temp = 57.5°C
Testing fluid: Water 7°C	Fluid outlet temp = 23°C
Power = 400 W	Simulation Time = 2 minute snapshot
Initial Coil temp = 20°C	



Plot 1: SOLIDWORKS simulation showing electromagnetic coil cooled using natural air convection under atmospheric conditions.
(snapshot at t = 120 seconds, 400 W heat generation)

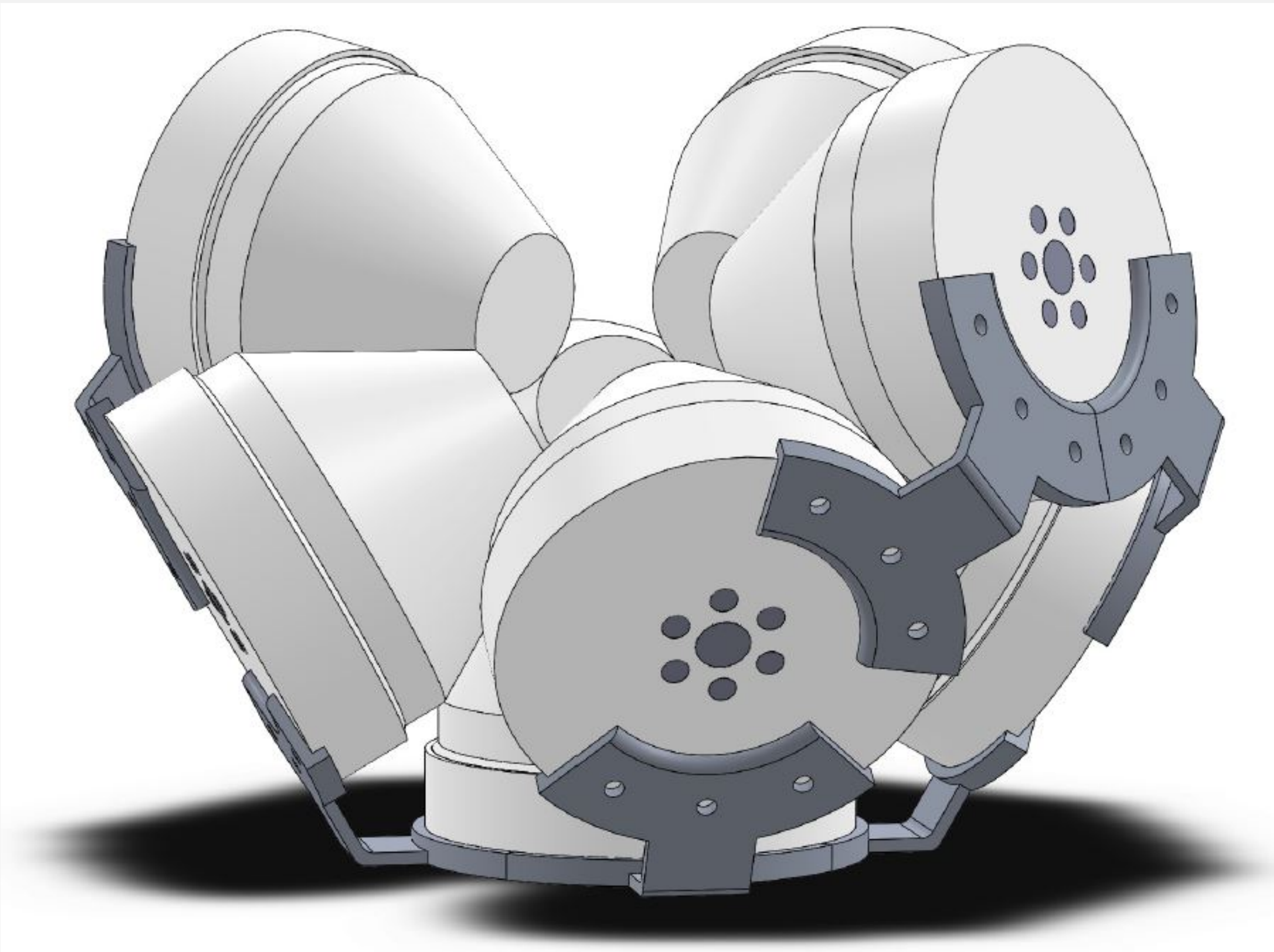


Plot 2: SOLIDWORKS simulation showing electromagnetic coil temperatures using cooling sleeve with water pumped from a chiller at 280 K.
(snapshot at t = 120 seconds, 400 W heat generation)



Plot 3: SOLIDWORKS simulation showing coolant (water) temperatures from the simulation in plot 2.
(snapshot at t = 120 seconds, 400 W heat generation)

V. Electromagnetic Coil Arrangement



Assembly model showing the final orientation and connections of the eight-electromagnet array. The work space is located at the center of the array.

VI. Physical Testing

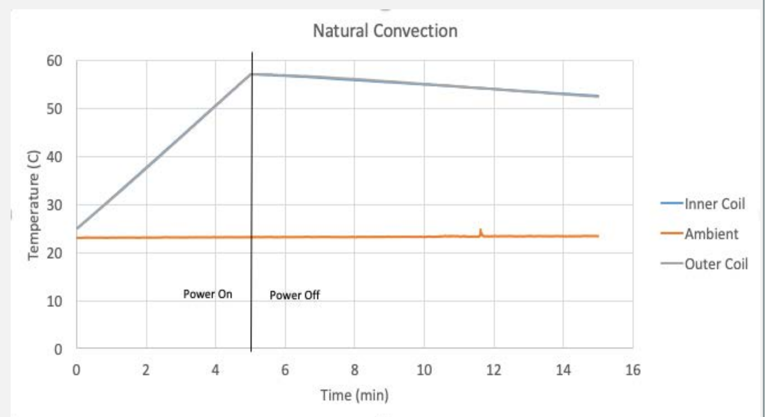
Test set-up:

- Thermocouples located in outer and inner layers of magnetic coil.
- Constant electric current passed through coil for 5 minutes to simulate use of haptic device and generate heat.
- Temperature monitored during 5 minutes of heating and 10 minutes after power was removed from coil.
- All tests began with coil at room temperature.
- Flow rate: 0.116 L/s; Inlet Water Temperature: 6°C

VII. Results

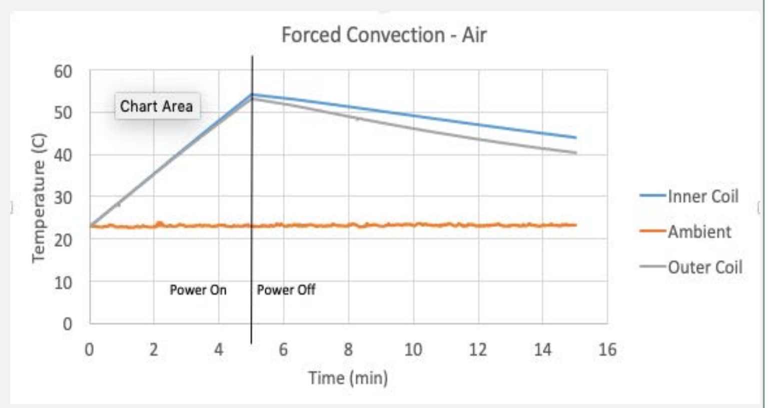
Test 1: Natural Convection to Ambient Air

- Results: Max temp of 59°C and rising.
- Will not meet constraint of 60°C
- Did not reach steady state.
- Heating Rate: 0.105°C/s
- Cooling Rate: 0.002°C/s



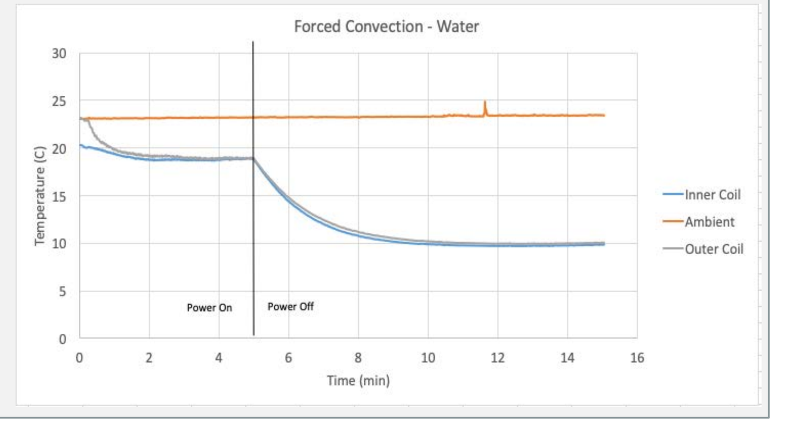
Test 2: Forced Convection with Air

- Results: Max temp of 54°C and rising
- Will not meet constraint of 60°C
- Does not reach steady state.
- Heating Rate: 0.093°C/s
- Cooling Rate: 0.050°C/s



Test 3: Forced Convection with Water

- Results: Max temp of 23°C
- Meets constraint of 60°C
- Reaches steady state.



VIII. Conclusion

Forced convection with the designed cooling sleeve provides the most efficient cooling method in each of the tests shown. This design will be applied to the final Untethered Haptic Magnetic Interface and will make up the overall cooling system. This design, along with the non-ferromagnetic frame prototype will become the building blocks for future work to complete the design of the Haptic interface.